Service Flow Networks for Functional Design of Distribution Centers

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***Abstract*—This work deals with the determination of an approach for concept planning of distribution centers. For this purpose, the "Distribution Center Design Process" is defined. Solution concepts for logistics centers are developed and evaluated in an eight-step process. In particular, it will be focused on formalization of the functional area, which has not been considered scientifically, yet. This results, among other things, in the definition of services and basic transformation properties of handling units. These can be used to create and semantically test service flow networks, which describe the functional sequence and transformations of service objects in distribution centers.**

***Keywords*—distribution center, conceptual design, service flow networks, functional design**

I. Introduction

Distribution centers[1], although sometimes described as a „necessary evil“ in the quest for leaner supply networks, proved for various reasons to be an indispensable component and decisive for the success and failure of modern supply networks. In recent decades, they have developed from storage facilities into integral components of global supply and value-added networks in which a wide variety of services is offered (e.g. consolidation functions in cross-docking systems, provision of value-added services from labeling/price labelling to product assembly in the sense of a postponement point or centers for the collection of returns).

Designing distribution centers is a complex and ill-structured decision problem, which is carried out by interdisciplinary teams. Because of the lack of mathematically optimal solution for these types of problems, the designers can only hope for a good solution. Hence, a central task of systematic design is to overcome the structural deficiencies. This is done by decomposing the problem into sub problems as well as modelling and abstracting these (sub-)problems. From the fact of the structural deficiencies follows that the legitimation of the planning result is caused by the intersubjectivity of the heuristic used. This also means that the derivation of heuristics – as far as possible – meets the requirements of formal rationality, i.e. the process of decision-making should be rational, while the goals guiding the process may be subjective. Thus, the scientifically founded derivation of the partial problems, their arrangement in a planning process as well as a suitable documentation of these contents are tasks of outstanding importance for the quality of the planning results.

II. Status Quo in Distribution Center Design and Central Questions

In regard to this background, it is not surprising that efforts have been made, both in practice and in research, to equip distribution center planners with tools to design optimal distribution centers. Nevertheless, it can be said that concrete examples of the broad application of research results are difficult to find [1]. Various authors state that scientific publications on the topic of designing distribution centers are not feasible [2], [3]. They cite the following reasons, among others:

- Research generally focuses on isolated problems which are often of little interest to the practitioner [1], [2], [4], [5].
- The exchange between research and practice is insufficient [1].
- In particular, the derivation of a comprehensive design process has so far received little consideration [4].

The state of research and development in the field of distribution center design can be summarized as follows: Nowadays, mainly individual case specific design processes are used, which are largely based on observations of design

[1] or warehouses

practice and personal experience. They are thus in strong contradiction to the analytical models of science:

"It is our opinion that existing research is not sufficient to support the design of a warehouse. As a result, facility designers that work in practice are left to face the design process with their own methods. These methods are in stark contrast to the analytical models developed in academia in that they are highly based on empirical observations. Supported by a collection of empirical observations, facility designers who work in practice employ an ad hoc design process." [3]

Therefore, the designing of distribution centers today is often not supported by state-of-the-art computer-based planning tools and is basically ad hoc. The lack of scientific support for the design process and standardized, formally defined design approaches hampers modern planning. A significant development on the way to improving the situation outlined above is the standardized representation of elements of a distribution center and their dependencies as well as the reduction of the informal area of planning [5], [6]. This work must lead to the scientific derivation and formalized description of a process model that is both practical and considers the character of the ill-structured decision-making problem. These potentials are here taken into consideration. Central questions in this context are:

- How should a process for the conceptual design phase of distribution centers be like?
- How can this process be made sustainable?

The goal of sustainable design is to be understood as a result of increased computerization, i.e. in an implementation in planning software.

Due to the multiplicity of possible design problems, the complexity of their solution as well as the multitude of principal technical solution possibilities, the implementation in a monolithic software approach is not practical. Rather, individual planning modules must be designed in such a way that they represent/solve self-contained planning tasks. At the same time, they should be able to be combined with each other as required within the framework of a modular planning tool set. This is in line with the trend in software engineering that has been valid for several years of modularization of previously monolithic software towards demand-oriented orchestration of small-scale software services and service-oriented architectures. The increase in design quality follows from the rejection of ad hoc models and planning processes specific to individual cases and the possibility of considering a larger number of variants.

III. Conceptual Foundations

The necessary prerequisite for the above described objective is the existence of a model world that is capable of defining consistent models and concepts for (continuous) support of the design process, as presented in [7]. The contribution of this work is made in the sense that only by formalizing a process to be followed in principle and the content to be used in this process, it becomes possible to be implemented in software: For each design phase certain concepts are used – functions, processes, resources, systems, etc.. These must be defined in their semantics. This significantly supports a collaboration of (different) software modules, but also of planners/engineers.

At the same time – and no less important – special attention is to be paid to formal rationality in the derivation of these contents. This is to be achieved by adhering to fundamental principles of system theory/systems engineering that have been tried and tested (for centuries).

A. Distribution centers as (complex) systems

The development of modern logistics is essentially characterized by system orientation and has developed on the basis of a systems approach based on operational practice [8], [9]. In logistics, the system perspective is generally concretized in such a way that logistics systems are understood as flow systems through which objects flow [8] or as transfer systems [10]. The general system theoretical concepts of system elements and their relationships are addressed in particular. At the same time, it is directly apparent that distribution centers have the characteristics of systems and especially the characteristics of technical systems [11].

B. Systems engineering and model theory

Another characteristic to be mentioned in this context is complexity. Complexity is here understood as the impossibility of accurately describing or predicting system behavior (within a reasonable time or through reasonable effort). Distribution centers are integrated into an entrepreneurial environment that is recognized as complex. The above aspects of complexity can also be found in distribution centers. Furthermore, the designing of distribution centers can be seen as a complex problem. To create above mentioned intersubjectivity, the design process of distribution centers as (complex) systems therefore should follow general principles of systems theory/systems engineering (as stated above).

C. Functional and physical object description

Systems can be described from structural point of view on the one hand, and from a functional orientation on the other. The structure view describes the integral quality, i.e. the condition of an object – it describes the physical area. In contrast, the function-oriented view describes the intended effect of objects on their environment; it is a description of the functional area and the description of functionality. Physical and functional descriptions can be seen as complementary descriptions of an object. They focus on different aspects. It is usually relatively easy for people to visualize physical descriptions in their inner eye – even if the object described never existed. If the description of the physical object area is complete, all information for creating the object is available (at least theoretically). There is thus an isomorphism (a one-to-one relationship) between the complete description of the physical object and the physical object itself [12]. A functional description, however, formulates descriptions of objects on an abstract and solution-neutral level – a direct idea of the described object is therefore difficult: "[…] to a functional description there corresponds a whole set, perhaps with infinitely many members of different physical objects that all have the same functionality. If we call the totality of all functional descriptions of objects the functional domain, and the totality of physical descriptions the physical domain, then we see that neither the mapping from the physical to the functional domain nor its inverse is single-valued." [12]. The idea of an action is most likely to apply to functions or functionality. Again, it is difficult to imagine an action without the object performing the action. To describe the physical effects of objects that represent the main aspects of functionality considered - in the design of technical systems in general and the rough planning of distribution centers in particular - we recommend to replace functionality with the term *service*. It follows that the descriptions of functions and functionalities represent the primary entities of a technical system, while the physical object itself (here: the technical system) and its descriptions are secondary entities – they are derived from the primary description. Any number of physical descriptions can be assigned to a function description – it defines a certain set of function-equivalent physical objects. The description of the functionality can be assumed to be complete if it expresses all functional requirements of the (future) users of the physical object, i.e. the client of the designer. According to [13], the relationships between functional and physical object descriptions can be expressed using the set algebra as follows:

A model of a system Σ consists of a quadruple of sets, the set of attributes A, the set of functions Φ, the set of parts K and the set of relations Π.

$$\Sigma = (A, \Phi, K, \Pi) \tag{1}$$

The quadruple Σ consists of two pairs, each of which represents a set of elements and a set of relations across the elements. The first pair describes a functional system ΣF, consisting of attributes A and relations Φ between the attributes. The second pair is called a structural system ΣS, consisting of parts K and relations Π between the parts:

$$\Sigma\mathrm{F} = (\mathrm{A}, \Phi)\ \text{mit}\ \mathrm{A} = \{\alpha_j\}\ \text{und}\ \Phi = \{\phi\_q\}\,;\ \phi_q \subset \mathbf{X}\, a_j\,;\ \text{j und q} = 1 \ldots \mathrm{n} \tag{2}$$

$$\Sigma\mathrm{S} = (\mathrm{K}, \Pi)\ \text{mit}\ \mathrm{K} = \{\kappa_j\}\ \text{und}\ \Pi = \{\pi_q\};\ \pi_q \subset \mathbf{X}\, \kappa_j\,;\ \text{j und q} = 1 \ldots \mathrm{n} \tag{3}$$

The structure of a system determines its functions (law of function determination, see formula 4) and cannot be concluded from a given function to the structure. The function of a system can be generated from different structures ΣS_j (law of equifunctionality, see formula 5). Therefore, several function breakdowns are possible for each function.

$$\forall\, \Sigma\colon \Sigma\mathrm{S} \rightarrow \Sigma\mathrm{F} \tag{4}$$

$$\forall \Sigma\colon \neg\, (\Sigma F \rightarrow \Sigma\mathrm{S}),\ \text{weil}\ \exists\ (\Sigma\mathrm{S}_1, \Sigma\mathrm{S}_2, \Sigma\mathrm{S}_3, \ldots),\ \text{so that}\ \forall\ \Sigma\mathrm{S}_j\colon (\Sigma\mathrm{S}_j \rightarrow \Sigma\mathrm{F}) \tag{5}$$

For these reasons, the structuring and systematization of distribution center planning should start with functional design.

D. Design procedures in systems and software engineering

A large number of different publications exist to support decision-making in the designing or adaptation of intralogistics systems, which can be fully or partially assigned to the area of concept design of distribution centers. They can be distinguished as follows:

1. Description of design procedures, partly in combination with knowledge-based methods or knowledge-based approaches (expert/assistance systems) and discursive methods
2. Approaches or methods for technique selection (usually descriptive models)
3. Approaches to dimensioning and arrangement/layout-finding (descriptive and prescriptive models)
4. Approaches to the evaluation of designed (sub)systems with regard to the fulfilment of the requirements placed on them and their amount for target achievement (descriptive and prescriptive models)

While a large number of publications can be found in German language and in international literature in the area of the approaches mentioned under point (3), the systematic derivation or definition of design seems to be particularly important in the German-speaking region (point 1 of the list). The following conclusions can be drawn by analyzing the publications from the above categories:

- The design steps described are largely similar, although the terms used and the level of detail chosen may differ. Even within a model, the level of detail can vary considerably along the phases.
- A derivation of the steps per se, a justification for the chosen sequence or a comparative consideration with alternative approaches are missing [14], [15], [16]. In other approaches they are derived directly from planning practice [04] or represent method-specific extensions of existing approaches (e.g. [3], [6], [17]).
- Basic structuring parameters of systems theory (e.g. a classification into life and project phases) are partly neglected.
- Central design principles of the description and design of systems are neglected, especially in approaches relating to distribution centers (but not exclusively here).

In the more recent scientific literature, no publication could be found that deals with the definition of a process for conceptual design of distribution centers, apart from method-specific adjustments or off the basis of practical planning [2]. The specification of domain-specific concepts/solutions can be

[2] The terms process and method are used in accordance to the Process-Method-Tool-Environment definition presented in [19].

determined in a series of papers. At this point it is important to note the standardization or definition of reference objects starts on the physical side of planning – the system view area, which in principle is characterized by an infinite variety of design options. A systematization of the functional description of logistics centers does not exist. A comparative comparison of the approaches with regard to the consideration of central aspects of systems theory and systems engineering is shown in Table 13. Based on this evaluation, the Systems Engineering Process [18] can be identified as a decisive starting point for defining a process model for the concept planning of logistics centers.

TABLE I. COMPARISON OF PLANNING APPROACHES WITH REGARD TO CENTRAL CRITERIA OF SYSTEM ENGINEERING

Central principles of systems engineering / Planning approach	Classification in a life cycle model	Consideration of iterations	Functional view	Structural view	Hierarchical view	Top-down-approach	Bottom-up-approach	Separation of functional and physical parts	Consideration of alternatives
Waterfall model	○	●	●	○	●	●	○	●	○
Spiral lifecycle model	○	●	●	○	●	●	○	●	○
V-model	●	●	●	●	●	●	●	●	●
Systems Engineering Process	●	●	●	●	●	●	●	●	●
VDI 2221	○	●	●	●	●	●	○	○	○
Warehouse Design Approach	○	●	●	●	○	●	○	○	●
Warehouse Design Workflow	○	●	●	●	○	●	○	●	●

● applicable

○ unspecified / not applicable

IV. DISTRIBUTION CENTER DESIGN PROCESS

The Distribution Center Design Process (DCDP) is a blueprint for model- and system-engineering-based concept planning of distribution centers. It represents a frame of reference, which structures the concepts to be considered – both in terms of their temporal occurrence (process structure) and their content and their interdependencies (structure).

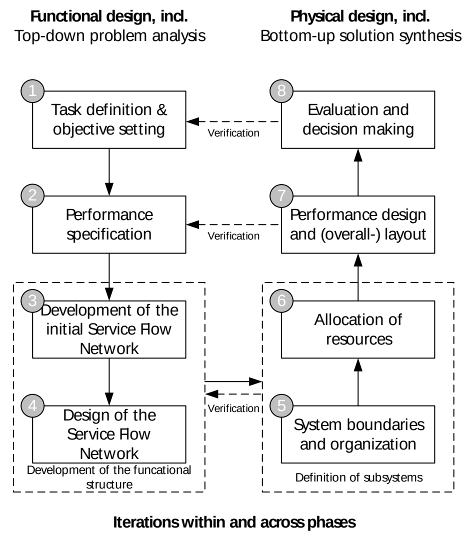

Figure 1: Structure and components of the DCDP

The DCDP is divided into two main areas: Functional Design and Physical Design. Through a top-down analysis in four steps the definition of the services that the distribution center has to provide to meet the requirements is carried out, starting with a definition of the task and objective (phase 1), followed by the specification of the performance requirements (phase 2) and finally the development of the functional structure (phases 3 and 4). This creates a hierarchical network of services (hereinafter referred to as the Service Flow Network). The target point of service decomposition (the service flow network) represents the transition from functional planning to the area of physical design (phase 5). For this purpose, system boundaries are defined along the identified services and the structure and process structure of the systems are defined. These are then assigned to components or resources as executing instances of the services (phase 6). Resources are designed with regard to their dimensions or the required number, integrated into an overall system (phase 7) and finally evaluated with regard to the quality of their suitability – i.e. in accordance with the target values established in phase 1 and subsequently rationalized (phase 8). The bottom-up synthesis of subsystems of an overall system results in the concept of a distribution center or the concept of a distribution center architecture. The recognition of the combinability of subsystems to an overall system, i.e. the consideration of the compatibility of the individual solutions or the partial solutions among each other is not unproblematic [20]. However, it represents the stringent implementation of the underlying principles.

Phases 1 and 2 of functional planning are to be carried out iteratively and in mutual agreement. Once they have been defined, they usually represent constants of planning. They are usually no longer subject to the iterative throughput of the subsequent phases. It is also possible to develop parallel solutions within the problem resolution process and the solution synthesis of phases 3-7 and finally to compare them in phase 8.

The phases of the functional and physical area are designed in such a way that the end point or output of the upstream phase becomes directly the input of the subsequent phase. At the same time, the result of the physical area represents a direct correspondence of the solution-neutral definition of the functional area. The functional specification becomes the measure of the quality of the physical solution developed. The phases of physical design are thus followed by a phase of verification or requirements comparison. These phases in turn trigger iterations.

Although the structure of the DCDP is described here sequentially, different processing is possible: as a step-by-step process-oriented or partially problem-oriented with subsequent or overlapping phases.

V. Functional Design Using Service Flow Networks

The development of the basics for the creation of a Service Flow Networks (SFN) is guided by various questions:

- How is the decomposition embedded in the DCDP?
- Which structural properties of services exist?
- Which services basically exist in logistics centers, i.e. from which stock can the planner of a logistics center use when creating a service flow network and up to what granularity should a decomposition take place?

A. Embedding of service flow networks in the DCDP

Based on the definition of tasks and objectives (phase 1) and the performance specification (phase 2), a Service Flow Network (SFN) is created in the third and fourth phase.

A service describes the intended effect of objects on their environment in a solution-neutral manner (see III.C). In contrast to a classical understanding of processes, information on their implementation (decision logic/methods, resources) is initially abstracted. The service analysis and the subsequent service design serve as an introduction to the subsequent design of systems (phase 5ff).

As part of a functional decomposition, the service of the distribution center defined at the outset is broken down into partial services. The SFN results from the logical linking of the partial services to a coherent network. The logical sequencing results in part as an inevitable consequence, since certain services must often be fulfilled before others can be used sensibly. The linking of services, i.e. the assignment of the respective incoming and outgoing quantities, is represented by the logistics service units, i.e. handling units such as loading or storage units. The analysis provided here only represents the starting point of structuring, i.e. system-forming measures and that at this point no conclusions are drawn with regard to a system structure, as was the case in the past, especially in the area of organizational science. The result of phase 3 is the simplest possible service flow network, i.e. the SFN that describes the minimum functional requirements for a logistics center. In individual cases it can be difficult to identify which SFN is to be modeled. In principle, no design decisions should be made (as far as possible). The components of the initial SFN should be limited to the necessary minimum.

While the activities of phase 3 essentially concerned breaking down and assigning the requirements brought to the distribution center from outside, decisions are required here that are also to be attributed to the creative process of developing solution variants. The requirements for the organizational structures, procedures and techniques/resources (phases 5 and 6) to be selected subsequently will be completed in phase 4. In order to adapt the SFN, consideration must be given to separating a service into at least two different services and to adding new services, including reallocation of incoming and outgoing material flows.

In contrast to the previous phase, in which it was assumed that the handling of articles (up to order composition) takes place in the form in which they enter the Logistics Center system or in which a direct transformation into the form of shipping took place through an order composition, the articles that subsequently make the same service requirements to the physical design of the system must be grouped (or clustered) here.

The creation of article groups and their assignment to services for the purpose of adapting the SFN is based on various features (in particular article characteristics/requirements as well as order and stock requirements). The methods used range from classification methods, i.e. the assignment of articles to predefined article groups, to uninformed methods for forming new groups without prior knowledge of the class (methods of cluster analysis).

With the completion of phase 4, a functional architecture of the distribution center has been created from the above-mentioned services. With the help of this functional architecture, the defined incoming currents can be transformed into the required outgoing currents. The services are checked for a suitable semantic context, i.e. the transitions offered by them can basically take place in the described sequence and deliver the required combinations. All services are specified in terms of their execution pattern and, if applicable, their absorption capacity. This is followed by the transition to the physical design of the defined services.

B. Structural properties of services

To meet the above requirement (i.e. the possibility of deriving necessary services and their frequency of execution), the concept of services must first be examined in more detail. The following properties apply to services, which are derived from the contents presented in the previous sections:

- **Self-similarity:** Services have the same or similar structures on the different hierarchy levels.
- **Coherence:** The descriptive characteristics of services (their attribute) must show the coherence of services, i.e. the semantic/sensual context or compatibility. Central description aspects represent the incoming and outgoing movements of logistical service units (flows of handling units/material flows).

- **Material and function flows:** These service links must be specified in such a way that they are used to check the coherence of the developed service flow network.
- **Requirements:** Partial services are carriers of the requirements defined in phases 1 and 2. A mapping (of excerpts) of these requirements to (partial) services is required.

C. Definition of services in distribution centers

Theoretically, services can be broken down in such a way that only services exist at the lowest level of the service structure that cannot be further subdivided in terms of general applicability. According to [21], the structuring should be stopped at a point where no concrete solution is indicated. Physical solutions (phases 5ff) are then sought for these services.

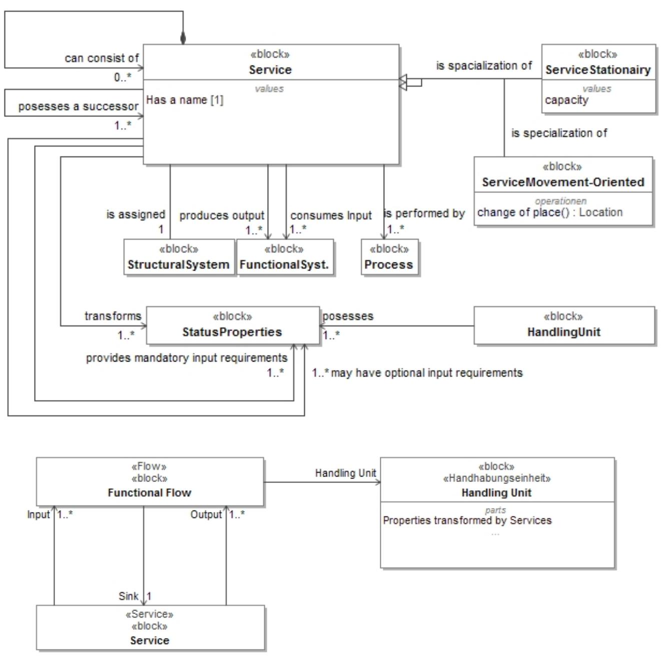

Figure 2: Service and functional flow definition

From a structural point of view, services can be differentiated on three levels. At the higher level (level 0) is the distribution-center-service, which makes general functional demands on a distribution center in the sense of a black box analysis. For this purpose, functional flows are essentially modelled which differ due to the top-level properties of handling units and the load carriers used. On the next level of consideration are services, which are generally referred to as functional areas (level 1). These are composed of the services of the third level (level 2). Service execute transformations on properties of handling units.

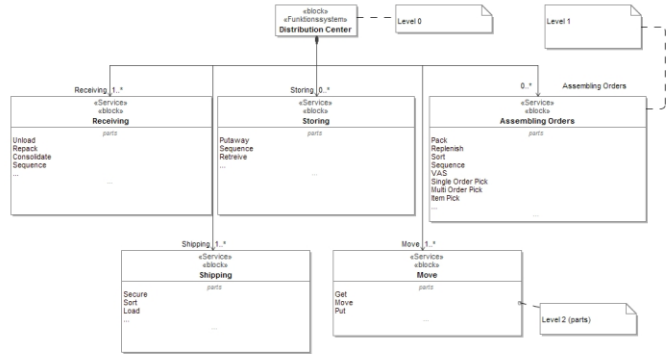

Figure 3: One possible definition of distribution center services

VI. Input-output definitions and service transitions for semantic checking of a service sequence

To create semantically correct SFNs, it is necessary to know the input and output conditions of services. Input properties represent those properties that handling units must have, so that a handling unit can be taken up by a service. In addition, output characteristics generated by service execution have to be defined. By doing so resulting service transitions (or the possible predecessor-successor relationships) can be identified.

The concept of transformations of properties of handling units and a definition of input requirements represent the solution space of valid / semantically correct service sequences. Valid SFNs can be created and/or checked (automatically) on this basis.

A. Example

Transformations on handling unit properties performed by services can mainly be represented by boolean variables (see Table II). The filled fields can be understood as mandatory requirements. Fields that are not filled can be defined as required (yes/no or 0/1) and are referred to as design requirements (i.e. depending on the designer´s preferences).
Table II also shows the output characteristics of handling units generated by service execution. The resulting service transitions are shown in Table III.

TABLE II. HANDLING UNIT PROPERTIES (SERVICE INPUT/OUTPUT)

Services			Properties																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Received	Need to be stored	Need for VAS	Loaded	Assembled for Shipping	Collection of multiple	Stored	Bufferd	Sequenced	Sorted	VAS requirement fulfilled	Partial Order	Ready to ship	Loading equipment	Location	Predecessor	Successor
1	Load	IN	y			n	y		n						y				
		OUT	n			y	y		y	y							new		n
2	Unload	IN	n			y			n									n	
		OUT	y			n			n		n	n					new		
3	Sort	IN	y			n			n		n	n		n	n				
		OUT	y			n			n	n	n	y		n	n		new		
4	Put-away	IN	y	y		n			n	n									
		OUT	y	n		n			y	n	n	n					new		6
5	Move	IN	y			n			n										
		OUT	y			n			n	n							new		
6	Store	IN	y			n			y	n									
		OUT	y			n			y										

TABLE III. RESULTING PREDECESSOR-SUCCESSOR RELATIONS

	Successor	1	2	3	4	5	6
Predecessor		Load	Unload	Sort	Put-away	Move	Store
1	Load	-	-	-	-	-	-
2	Unload	x	-	x	x	x	-
3	Sort	-	-	-	x	x	-
4	Put-away	-	-	-	-	-	x
5	Move	x	-	x	x	-	x
6	Store	-	-	-	-	-	-

VII. DISCRETE MODELLING OF CENTRAL RELATIONSHIPS AND STATEMENTS OF SERVICE FLOW NETWORKS

Let S_{LZ} be the service that a logistics center must provide and $S = \{s_1, ..., s_n\}$, with $|S| = 18$ the entirety of the possible services of a distribution center. Furthermore, $S = T \cup U$, with $T = \{t_1, ..., t_n\}$ is the set of all inpatient services and $U = \{u_1, ..., u_n\}$ the set of all movement-oriented services.
For the heuristic tool of splitting S_{LZ} into subservices $s_i \in S$ in phases 3 and 4 of the DCDP is to apply:

$$S_{LZ} \sim (s_1, s_2, ..., s_n) \qquad (6)$$

The relationship between services and (structure) system in system modeling can be defined as shown below. A system Σ can be described as part of a higher-level system Σ^+ [13].

$$\Sigma \subset \Sigma+ = (A+, S+, K+, \Pi+) \qquad (7)$$

The part κ_j of a system Σ can be described as subsystem Σ'.

$$\Sigma \supset \Sigma' = (A', S', K', \Pi') \qquad (8)$$

Be here $\Omega \supset \Sigma$ the multitude of the area under investigation. Then the environment I is the subset of the universe set that is not system [13].

$$I = \Omega \setminus \Sigma \qquad (9)$$

This definition can now be used to define input and output between a system and its environment. For this α_i, α_j are elements of the attribute set $A = \{\alpha_i, \alpha_k\}$. Furthermore $\iota \notin \Sigma$ is an attribute of the environment I of the system Σ. Then α_i is called input if it is in relation between environment and system $\iota \times \alpha_i$ as a descendant. α_j is called output when it is in a release between environment and system $\alpha_j \times \iota$ as a precursor.
It should also apply that the service term is used synonymously with function.

$$\Phi = S \qquad (10)$$

Thus, the definition of the model of a system (see formula 1) can also be expressed as a quadruple $\Sigma = (A, S, K, \Pi)$, where $\Sigma F = (S, A)$ can be described as a functional system and $\Sigma S = (K, \Pi)$ as a structural system. Services can now be defined as relations s_i between attributes α_i, α_j of a function system $\Sigma F = (A, S)$.

$$s_i \subset \alpha_i \times \alpha_j \qquad (11)$$

The attributes of the function system ΣF are interpreted as function flows within the DCDP. Furthermore, the following relationships apply to functional flows α: $\alpha = (M, \Theta, Y)$, with $\mu_i \in M$ attributes for describing the distribution of the flow, $\theta_i \in \Theta$, status properties of handling units and $\upsilon_i \in Y$, attributes for further specification of the description, each with $I \in N$.
The services s_i determined within the scope of service decomposition are linked to an SFN. An SFN G_{SFN} (A, S) is a directed graph with the node set A and the edge set $s_i \subset (\alpha_i \times \alpha_j)$, in which each node $\alpha_i \in A$ represents a flow and each edge $(\alpha_i, \alpha_j) \in S$ a transition between flows. The SFN defined in this way thus becomes a reflection of the functional system formulated in formula 2.

$$\Sigma F \leftrightarrow G_{SFN} (A, S) \qquad (12)$$

From the system definition and the law of equifunctionality (formula 6) and $\Phi = S$ different conclusions can be drawn for phases 5-8 of the DCDP. First, the assignment of systems to services is not unique:

$$\exists\, \Sigma: (S \rightarrow \Sigma), \text{ because } (\Sigma_1, \Sigma_2, ..., \Sigma_n), \text{ so that } \forall \Sigma_i\, (\Sigma_i \rightarrow S) \qquad (13)$$

This also applies to the result of an assignment $V \times \Sigma$ of procedure V, with $V = \{v_1, ..., v_n\}$ quantity of procedures to a system Σ. Furthermore, the above-mentioned context of the possibility of multiple assignment also applies to

- the definition of the organizational system, consisting of the organizational structure and process organization,
- to the choice of resource types,
- and to the assignment of resources to resource types.

VIII. Summary and Conclusion

Within the here presented work the conceptual design of distribution centers is tackled from two perspectives. As a result, the "Distribution Center Design Process" (DCDP) is developed. During an eight-step process, solutions for distribution centers are developed and evaluated, starting with the definition of tasks and objectives. The process is divided into two parts, each with four phases. First, one part of functional de-sign, which concerts the task description into a functional concept in the sense of a top-down problem analysis. Second, one part of physical design that con-verts this concept in the sense of a bottom-up solution synthesis into one or several evaluated solution proposals. In particular, the formalization of the functional area of the designing of lo-gistics centers has been focused. The concept of Service Flow Networks was developed and modelled.

The present work is a starting point for a series of research projects in various categories. First of all, further developments of the DCDP and its sub-models may be mentioned. This refers to work that does not fundamentally extend the area of application of the process model, but rather further details individual aspects or subjects them to critical examination.

The further development of the DCDP process model towards a methodology in the sense of the PMTE diagram presented in [19] remains open. Additionally, we would like to mention a development and implementation of an approach for the automated generation of SFNs of phases 3 and 4 on the basis of predefined requirements of phases 1 and 2.

IX. References

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